Anomalous γ-ray Emission Component in GRB 941017

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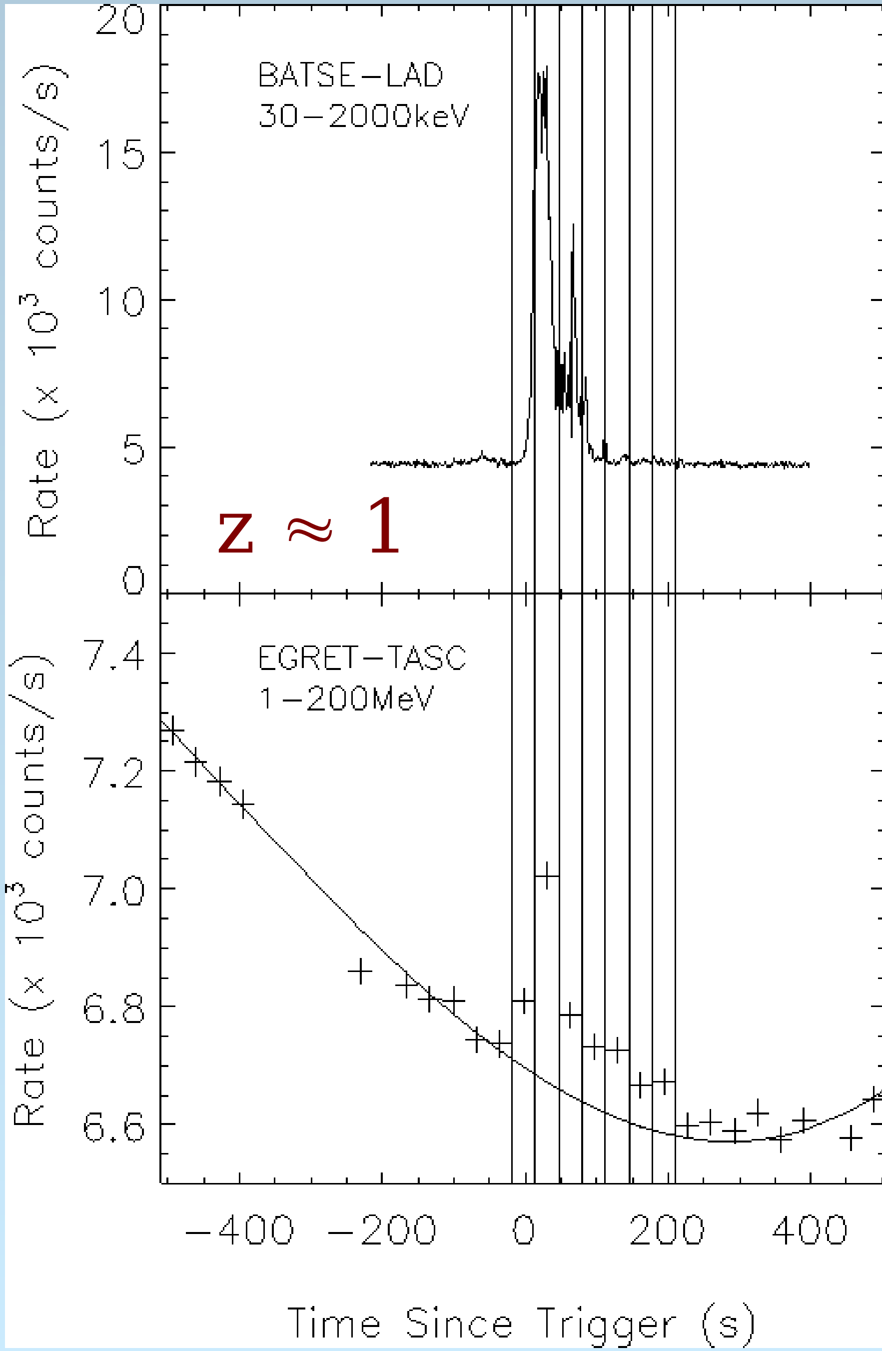
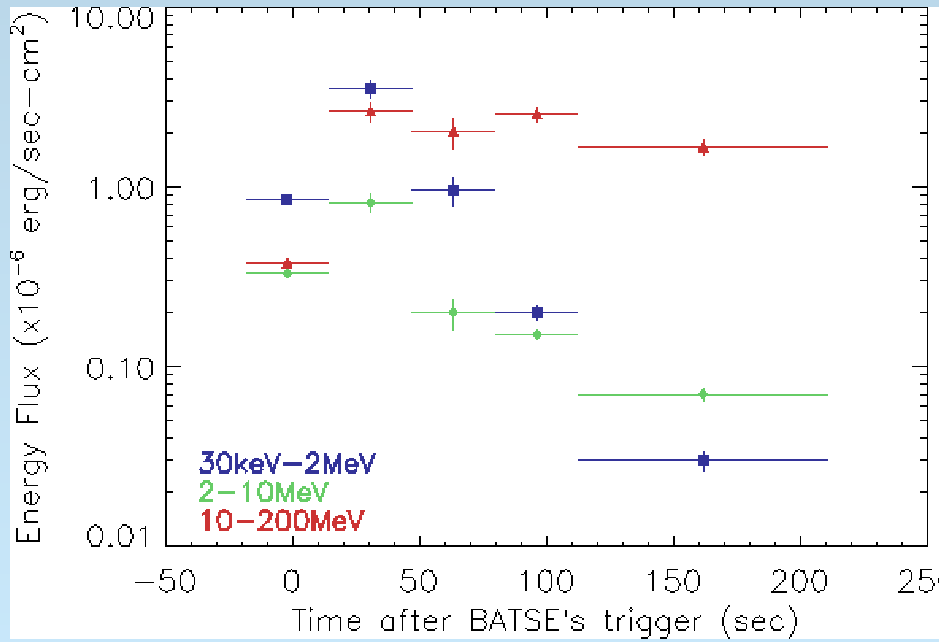
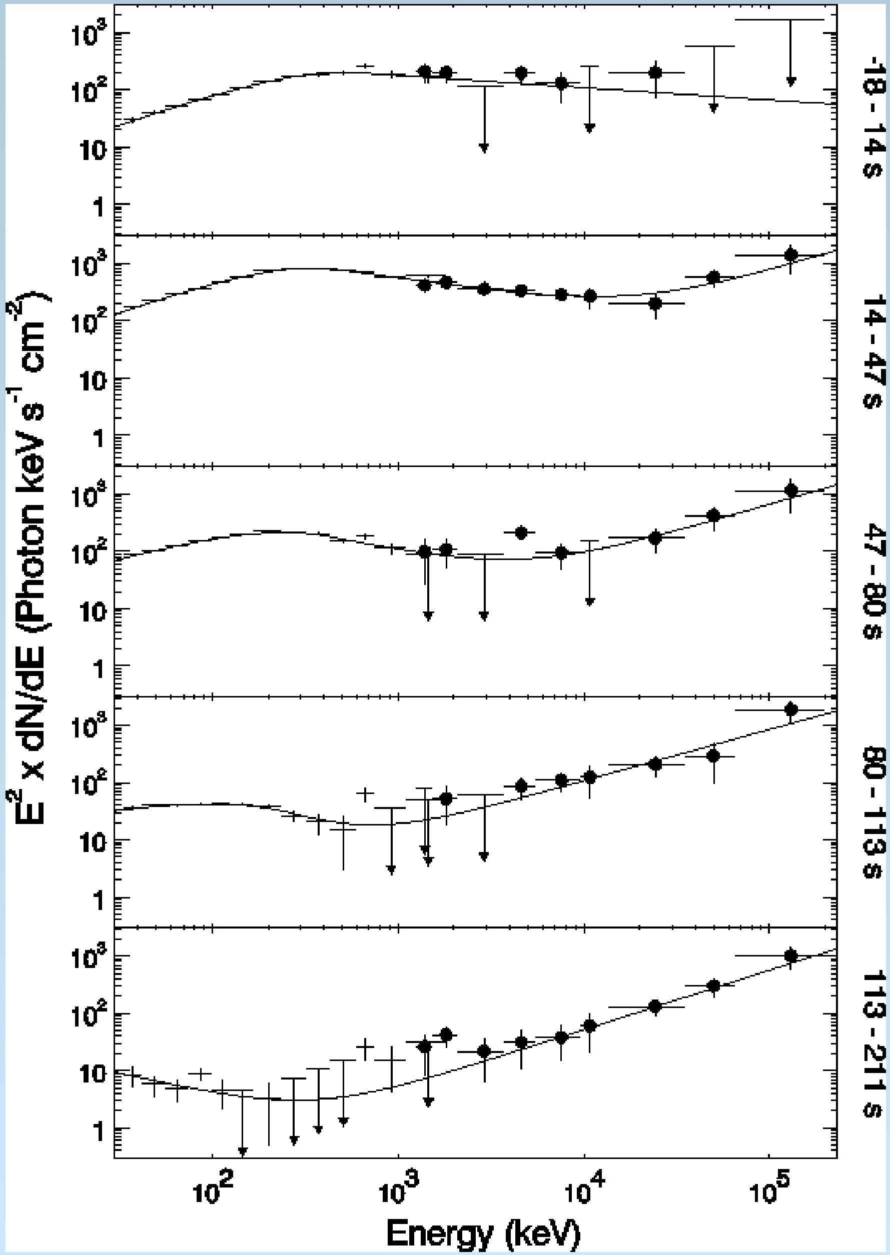
GRB 2003, Santa Fe, NM, Sept. 8-12,

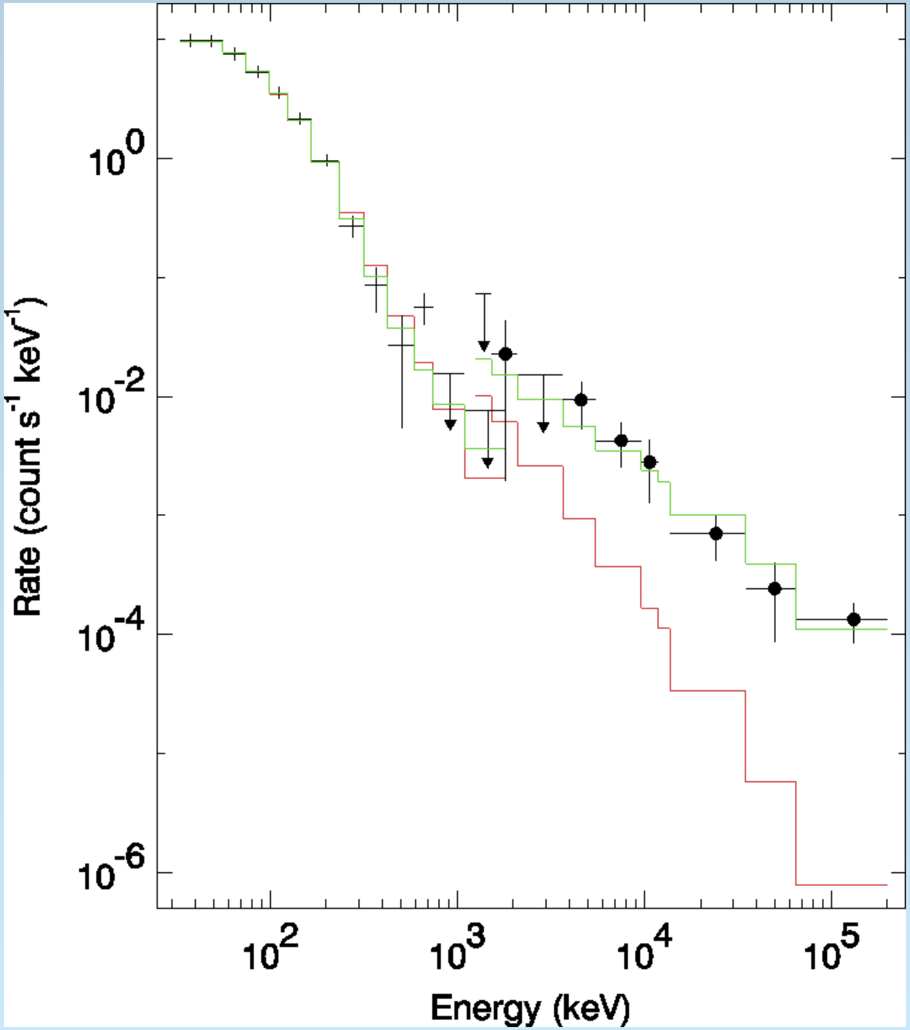




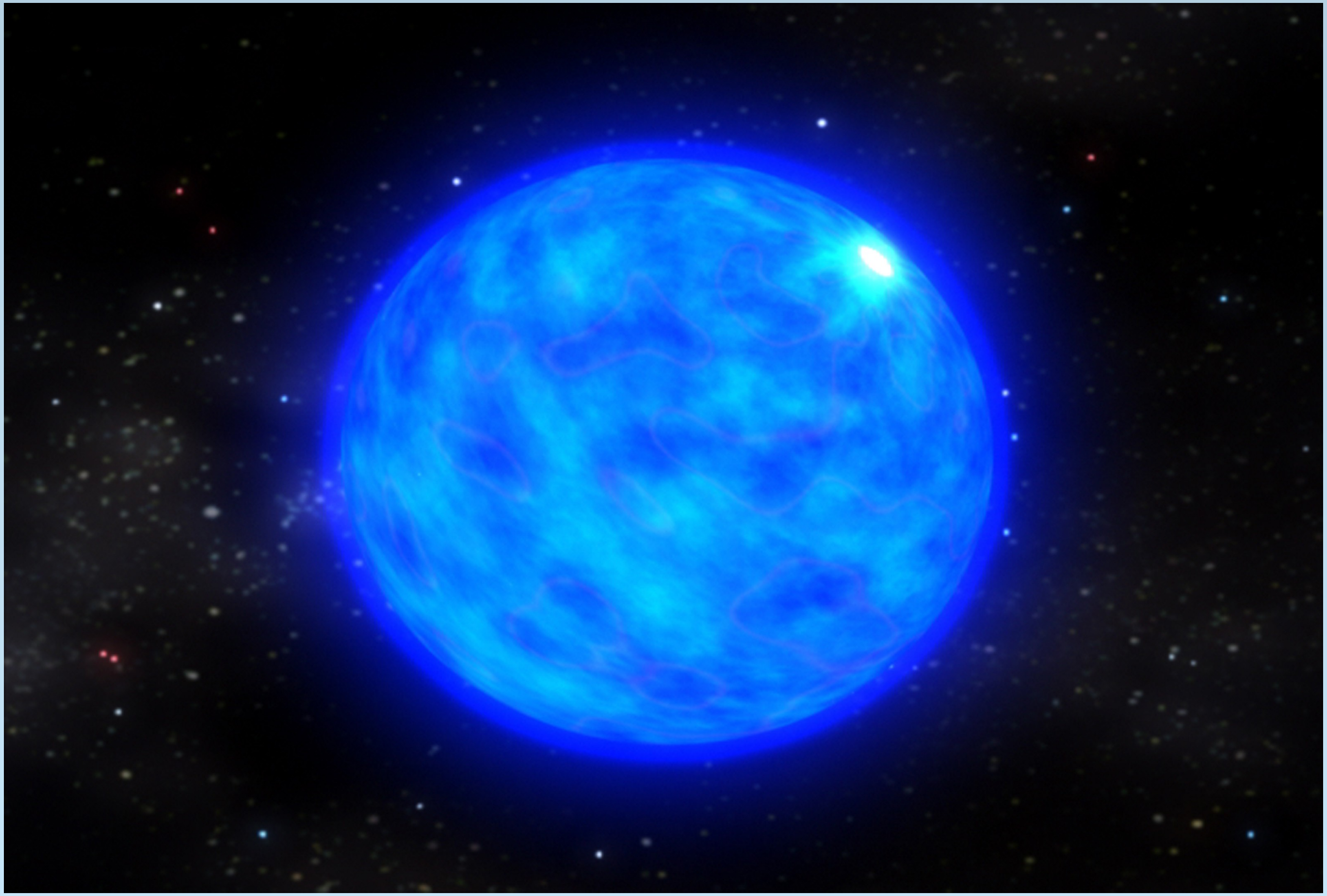
González, et al. (2003)

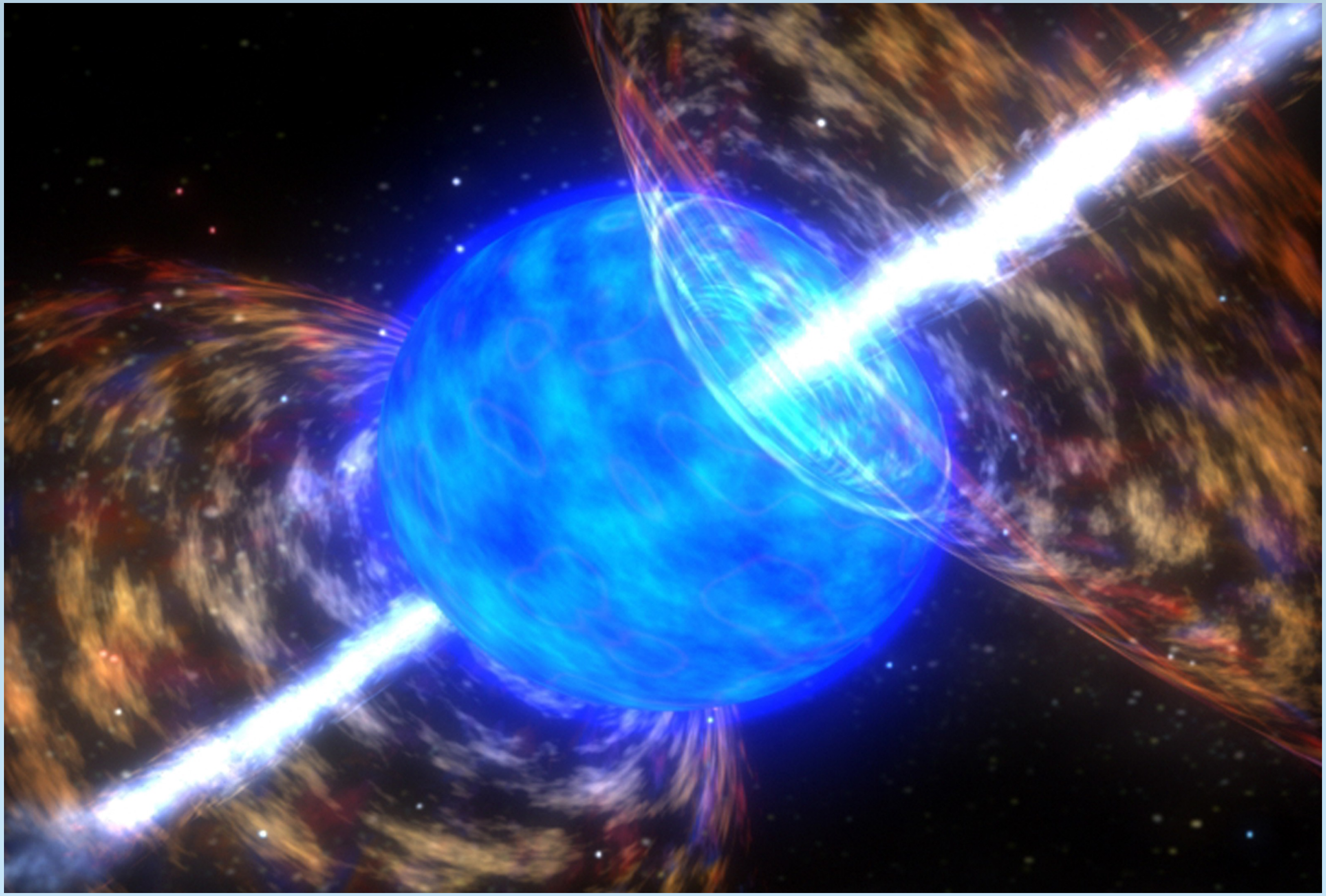
Hard Spectral Compone

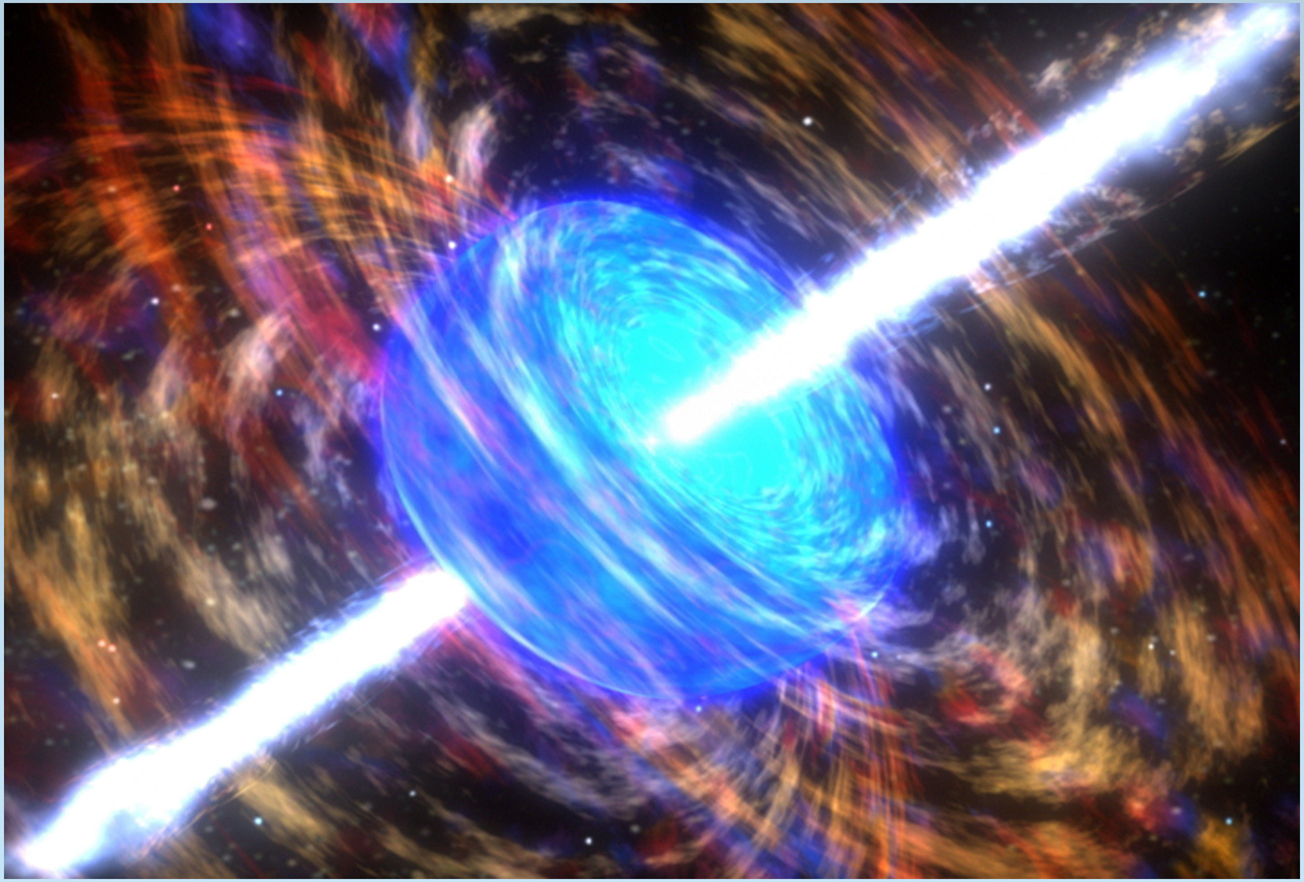


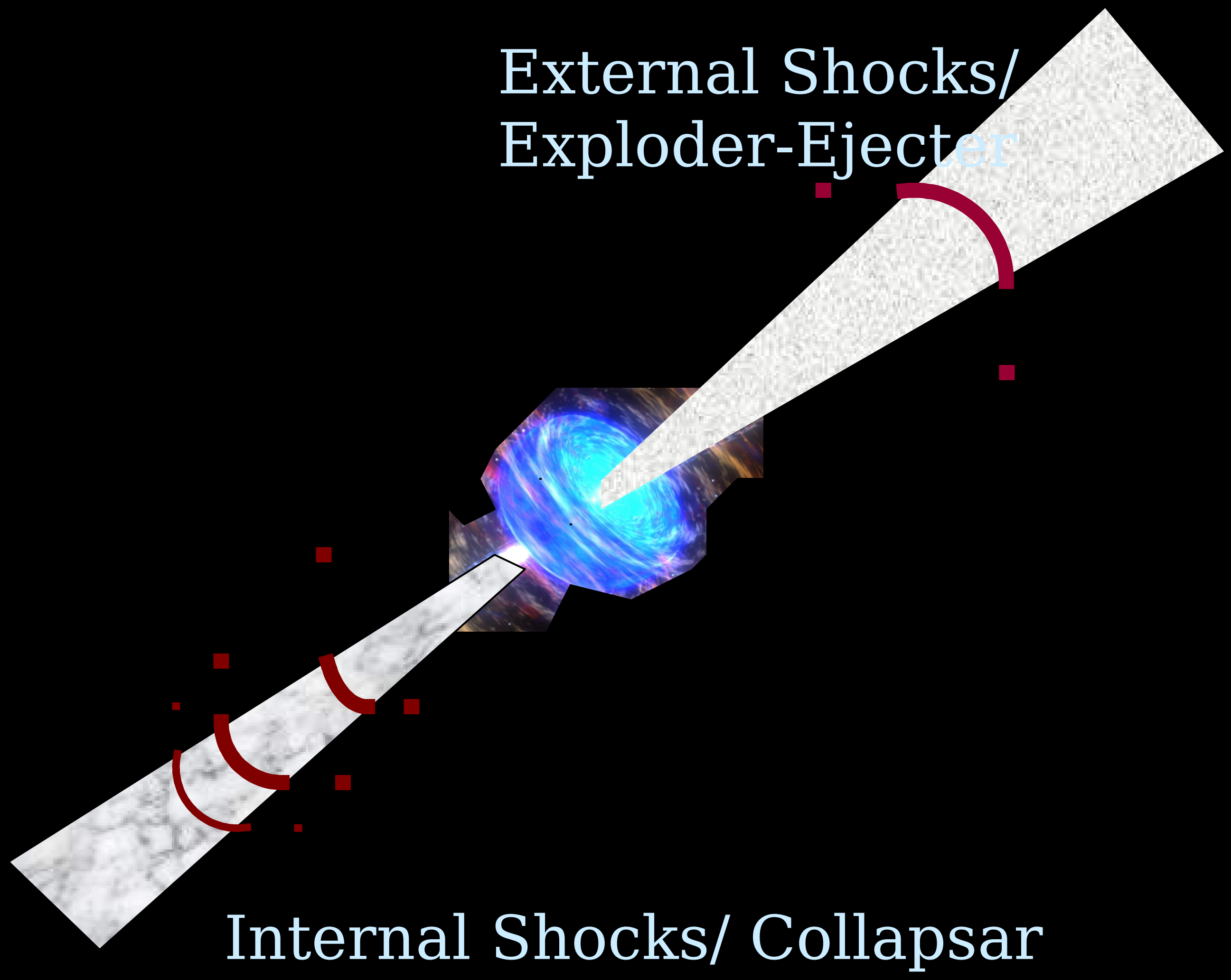


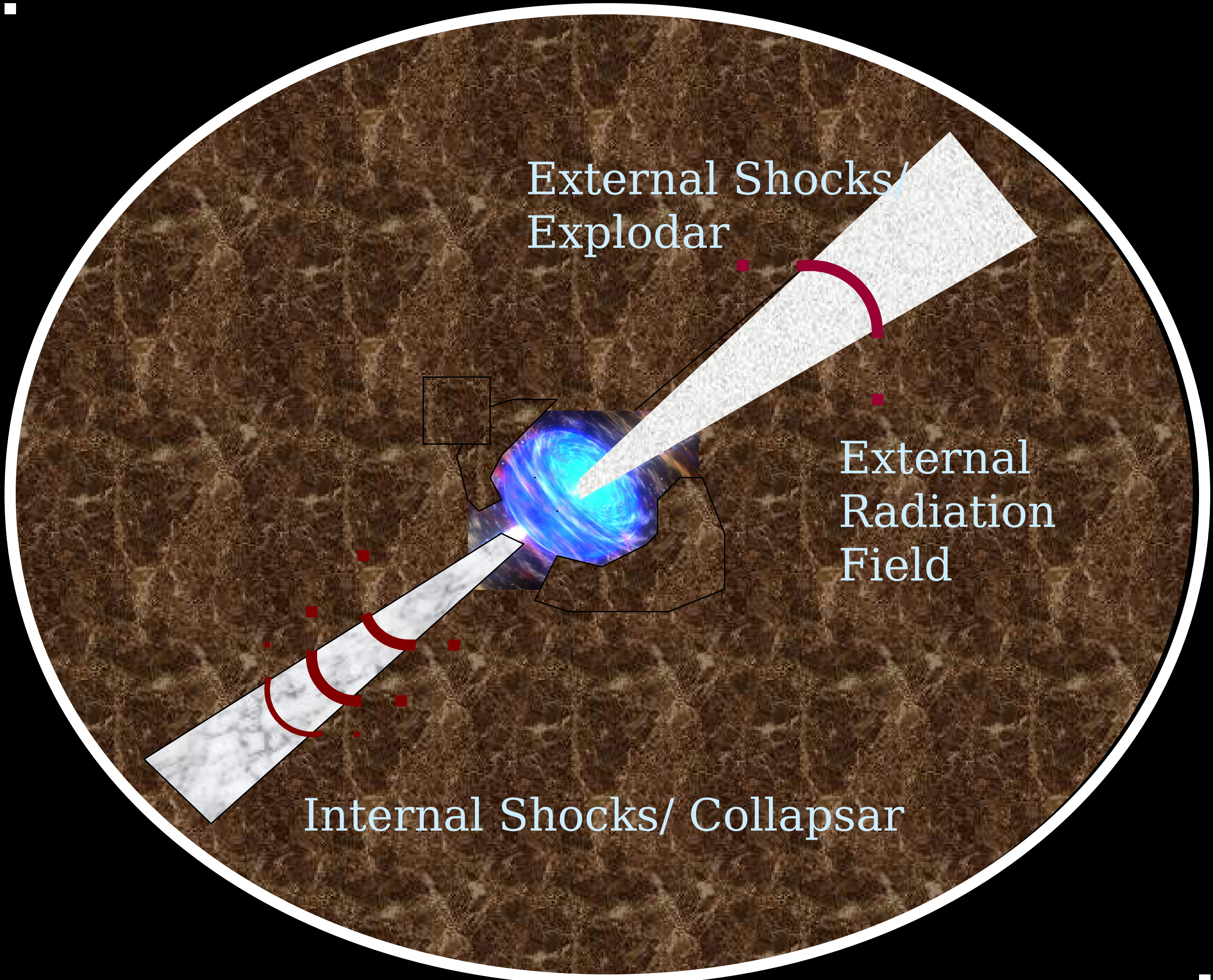
Hard γ-ray component reaches 10^{-7} – 10^{-6} ergs cm^{-2} s^{-1}








External Shocks/
Exploder-Ejecter
Internal Shocks/ Collapsar



External Shocks/
Explodar
External
Radiation
Field
Internal Shocks/ Collapsar

Fireball/Blast Wave Model for GRBs

- Leptonic Models (Mészáros, Rees, Paczynski, ...)

  Synchrotron, Adiabatic Expansion, Synchrotron Self-Compton, External Compton processes

Cascade Radiations from **$\gamma\gamma^* \rightarrow e^+e^-$** followed by **$e+B \rightarrow \gamma$, $e+\gamma \rightarrow e' + \gamma'$**

- Hadronic Models (Waxman, Vietri, Mészáros, Atoyan, Derm

  Photopion, Photopair, Hadron Synchrotron, Cascade Radiation processes

Cascade Radiations from **$N+\gamma \rightarrow \pi^0 \rightarrow \gamma, \gamma\gamma^* \rightarrow e^+e^-$, $e+B \rightarrow \gamma$, $e+\gamma \rightarrow e' + \gamma'$**

$\pi^\pm \rightarrow e^\pm$, followed by **$e+B \rightarrow \gamma$, $e+\gamma \rightarrow e' + \gamma'$**

(Photopion; similar cascades for photopair processes **$N+\gamma \rightarrow N + e^\pm$**)

Blast Wave Theory for Leptonic Models: Forward Shock

- Nonthermal synchrotron radiation in shocked fluid
  - Joint normalization to power and number gives

$$\gamma_{\min} \cong e_e\left(\frac{p-2}{p-1}\right)\left(\frac{m_p}{m_e}\right)\Gamma \; ; \; \dot{E}'_e = e_e(dE'/dt')$$

- Magnetic field parameterized in terms of equipartition field

$$\frac{B^2}{8\pi} \cong 4 e_B m_p c^2 n_* (\Gamma^2 - \Gamma) \Rightarrow B \propto \Gamma$$

- Injection of power-law electrons downstream of forward shock

$$\dot{N}(\gamma_e) = N_e \gamma_e^{-p}, \gamma_{\min} < \gamma_e < \gamma_2 \; (comoving \; \gamma_e)$$

$$N_e = 4\pi \, n_{ext} x^3 / 3$$

- Maximum injection energy: balancing losses and acceleration rate

$$\gamma_2 \cong 4 \times 10^7 / \sqrt{B(G)}$$

- Cooling electron break: balance synchrotron loss time with adiabatic expansion time

$$t'_{adi} \cong x/\Gamma c \cong \Gamma t \cong t'_c \cong \left(\frac{4}{3} c \sigma_T \frac{u_B}{m_e c^2} \gamma_c\right)^{-1}$$

$$\Rightarrow \gamma_c \cong \frac{3 m_e}{16 e_B n_* m_p c \sigma_T \Gamma^3 t} \Rightarrow \gamma_{\min} \propto t^{-3/8}, \gamma_c \propto t^{1/8}$$

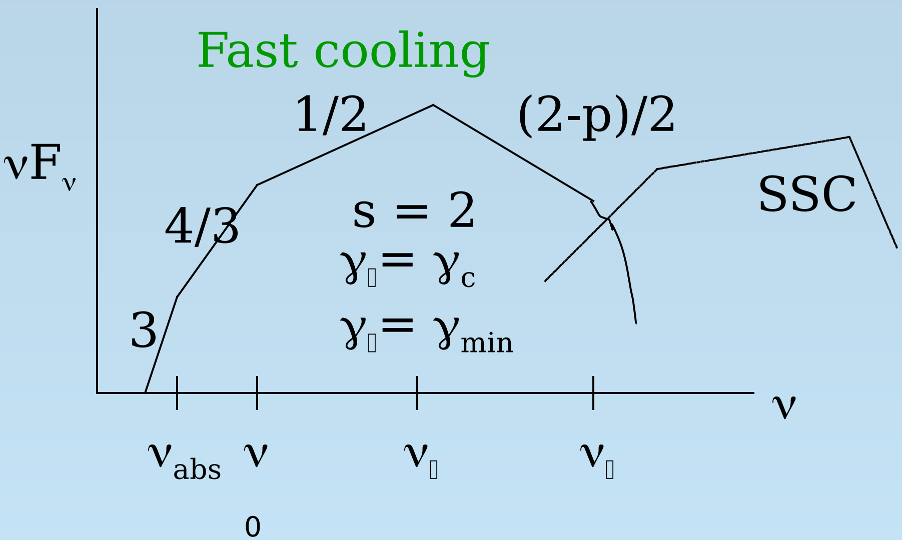
Spectral Energy Distribution

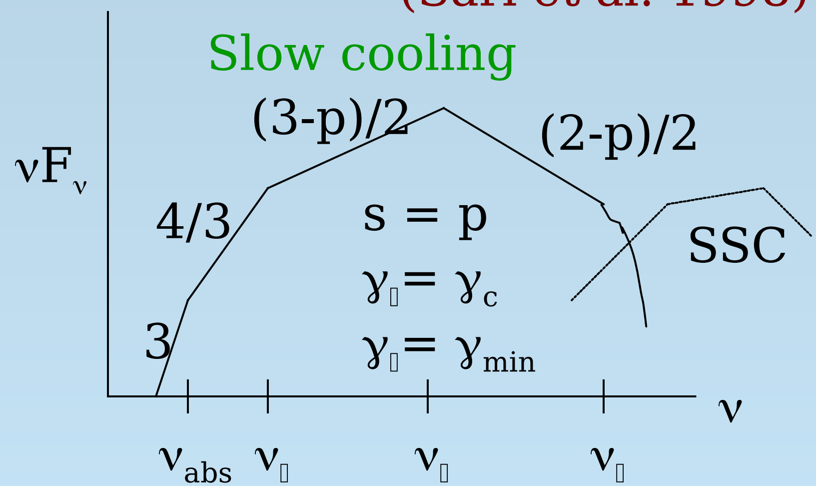
Evolving electron spectrum:

$$N_e(\gamma_e) \cong N_e \gamma_o^{s-1}\gamma_e^{-s}, \gamma_0 < \gamma_e < \gamma_1$$

$$N_e(\gamma_e) \cong N_e^o\, \gamma_o^{s-1}\gamma_1^{-s}(\gamma_e/\gamma_1)^{-(p+1)}, \gamma_1 < \gamma_e < \gamma_2$$

(Sari et al. 1998)





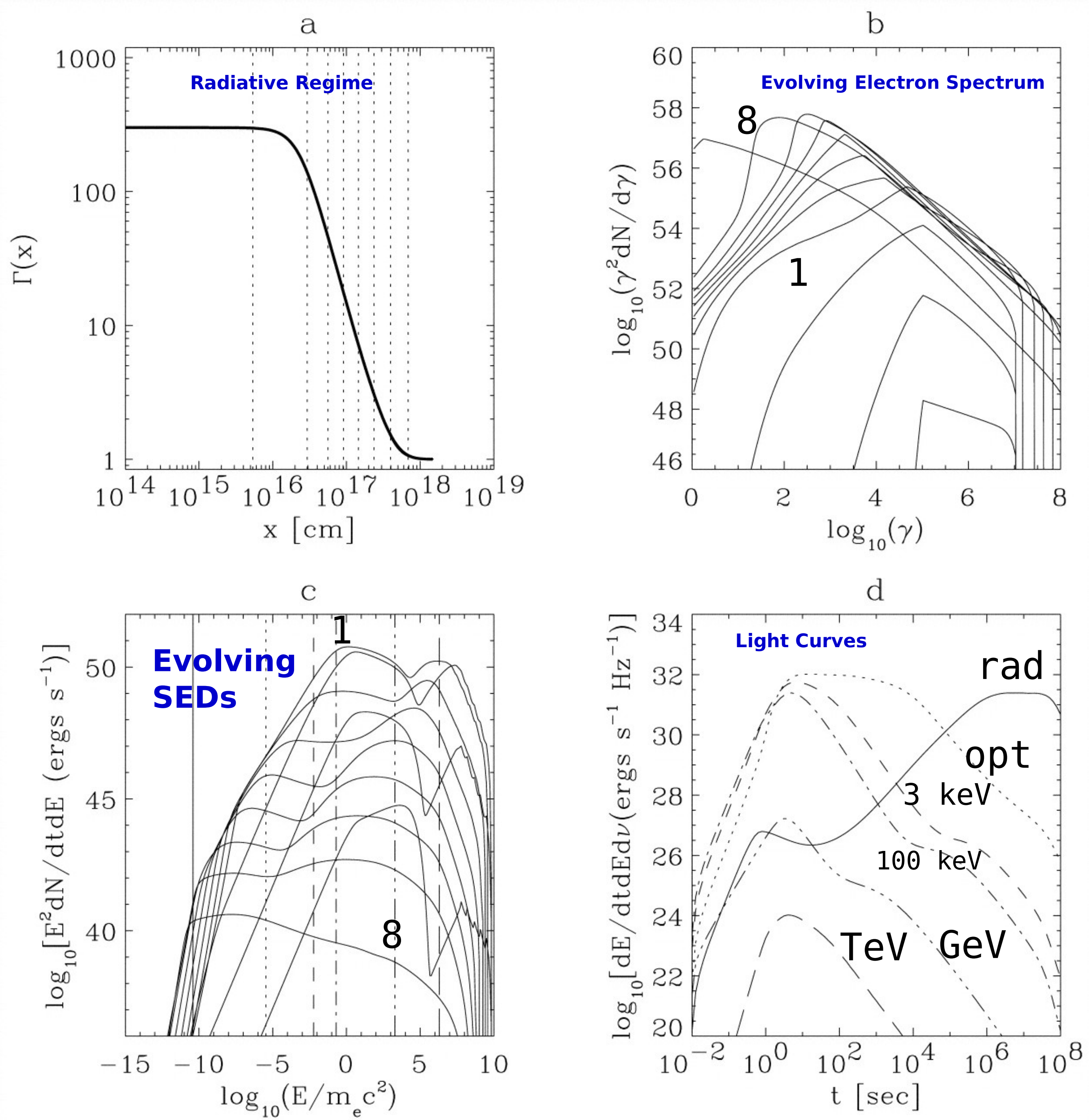
- 2 < p < 3
- SSC increasingly important when $e_B << e_e$
- Radial Density Gradients

$$\nu_i = \Gamma \gamma_i^2 eB/[2\pi m_e c(1+z)]$$

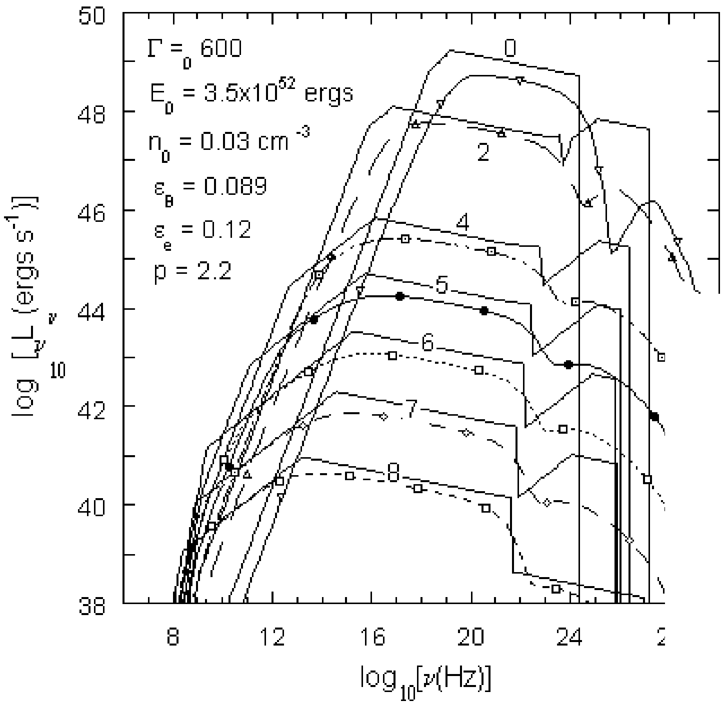
Numerical Simulation with Uniform Surrounding Medium;

Relativistic forward shock and non-relativistic reverse shock

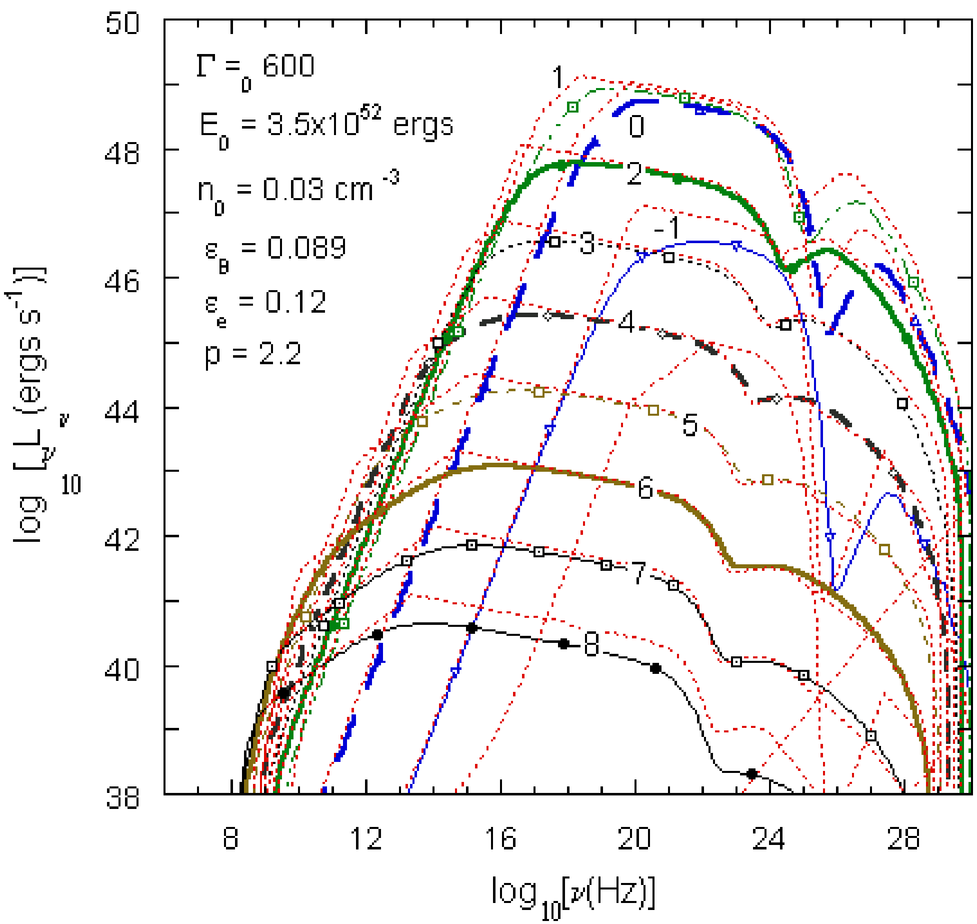
Chiang and Dermer (1999)

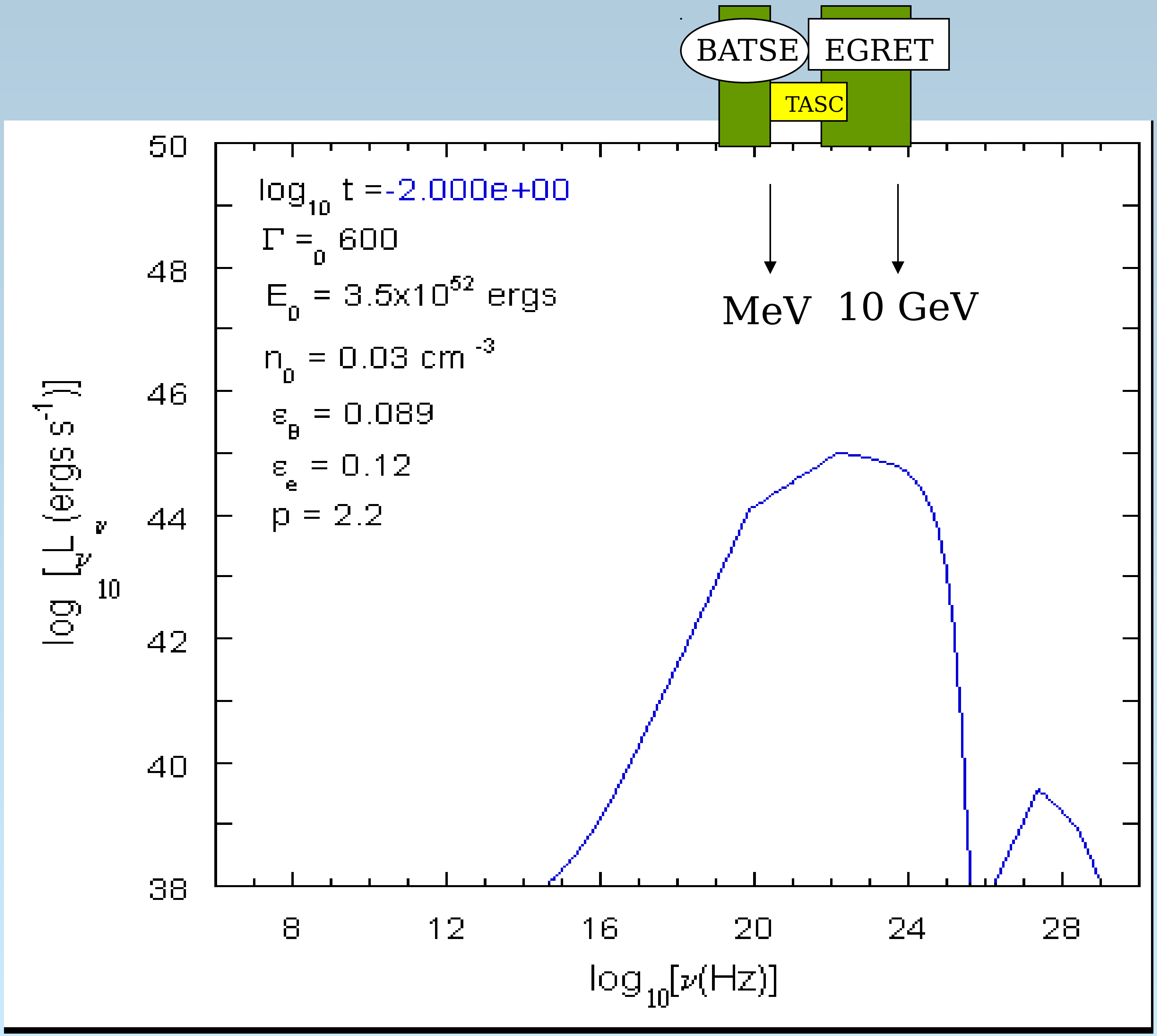


SEDs: Parameters of Wijers and Galama (1999) for



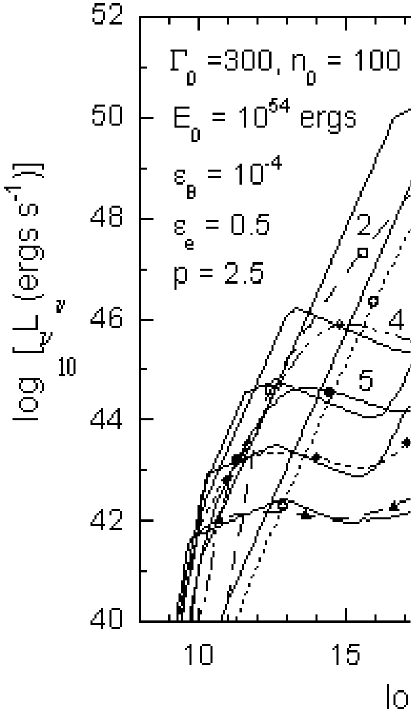
Dermer, Böttcher and Chiang (2000

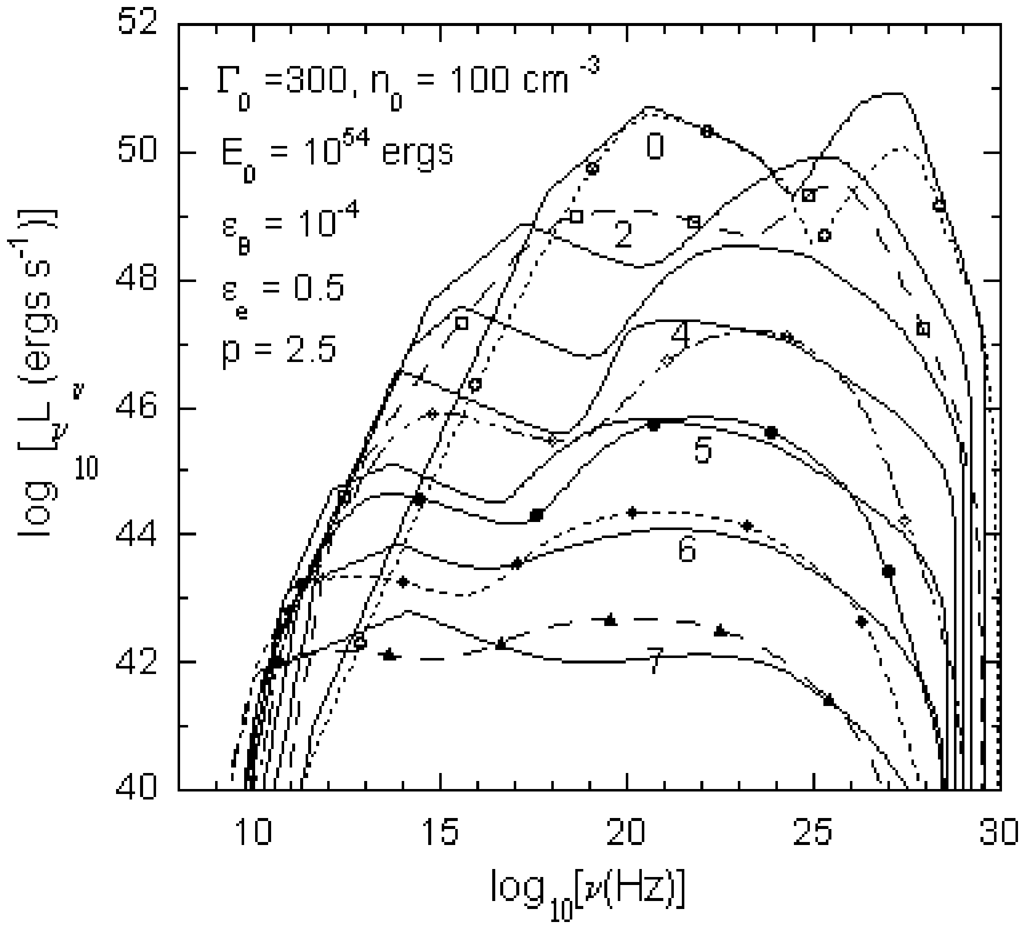




BATSE
EGRET
TASC
MeV
10 GeV
$\log_{10} t = -2.000e+00$
$\Gamma_0 = 600$
$E_0 = 3.5x10^{52}$ ergs
$n_0 = 0.03$ cm $^{-3}$
$\varepsilon_B = 0.089$
$\varepsilon_e = 0.12$
$p = 2.2$
$\log_{10} [\nu L_\nu (\mathrm{ergs\ s^{-1}})]$
$\log_{10}[\nu(\mathrm{Hz})]$
50
48
46
44
42
40
38
8
12
16
20
24
28

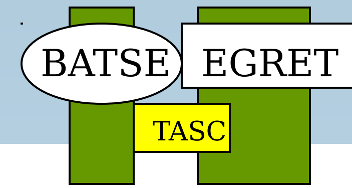
SEDs: Parameters of Chiang and Dermer (1999) for prompt phase



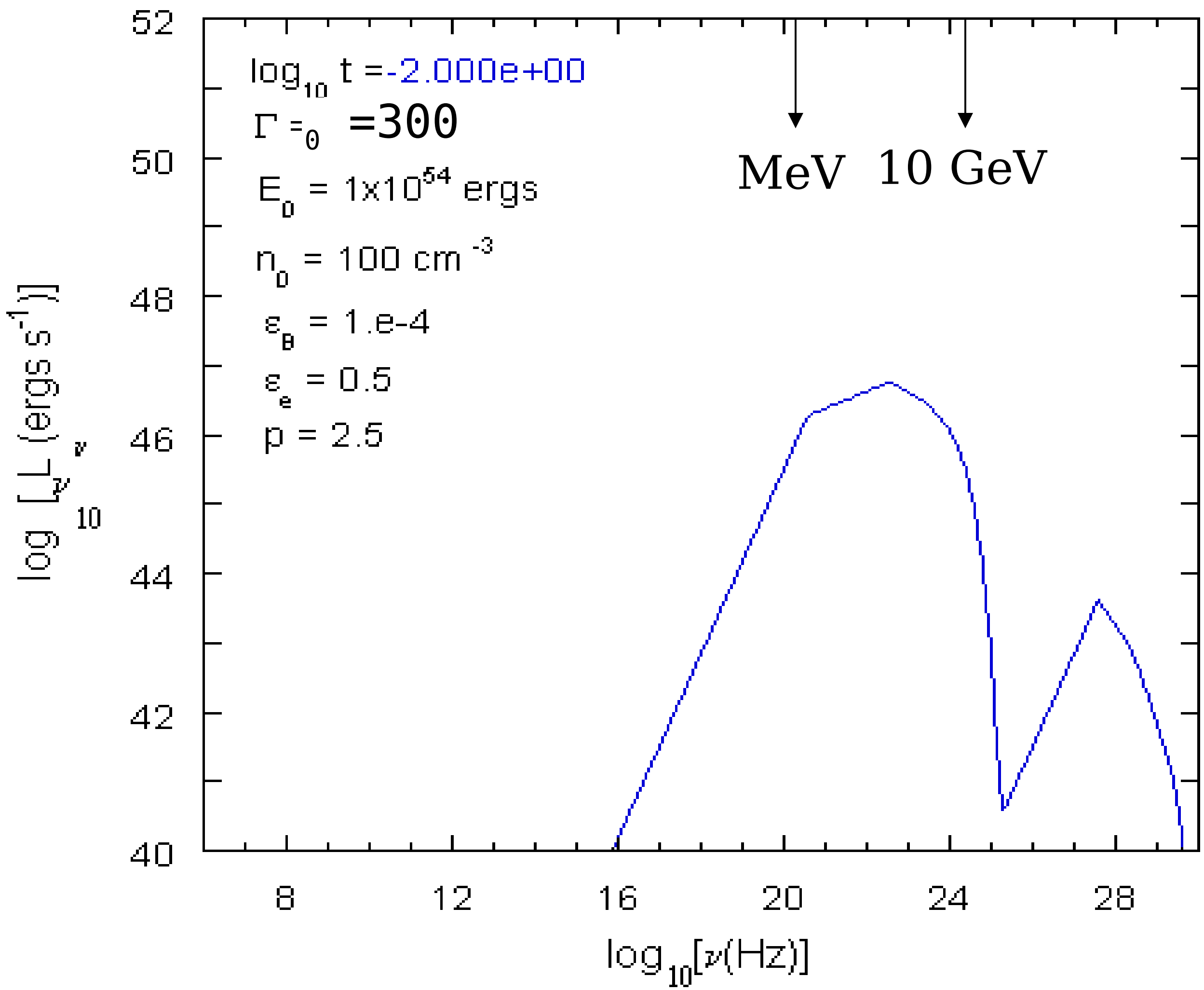


Dermer, Böttcher and Chiang (2000)

Γ_0 = 300

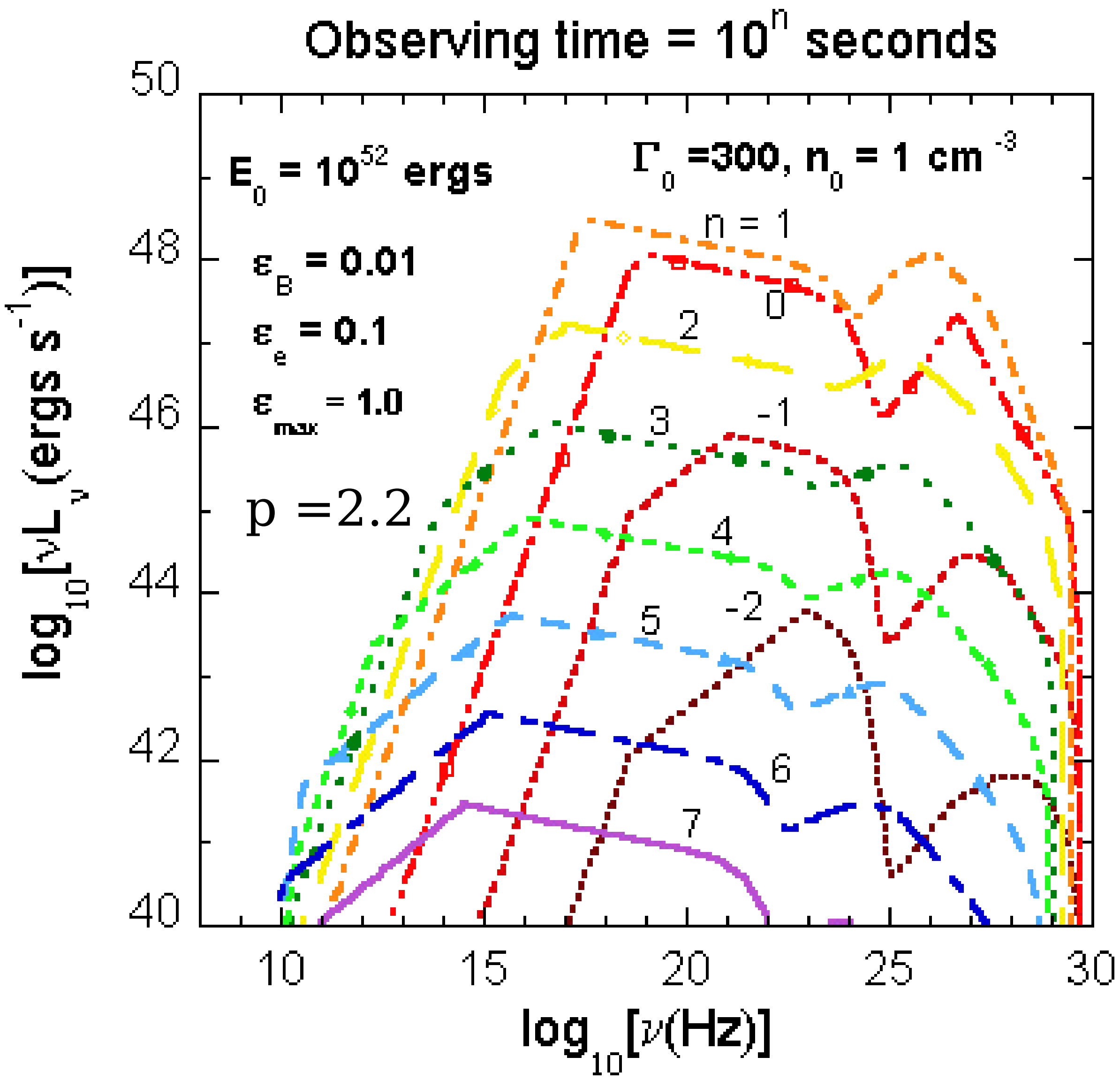


BATSE
EGRET
TASC

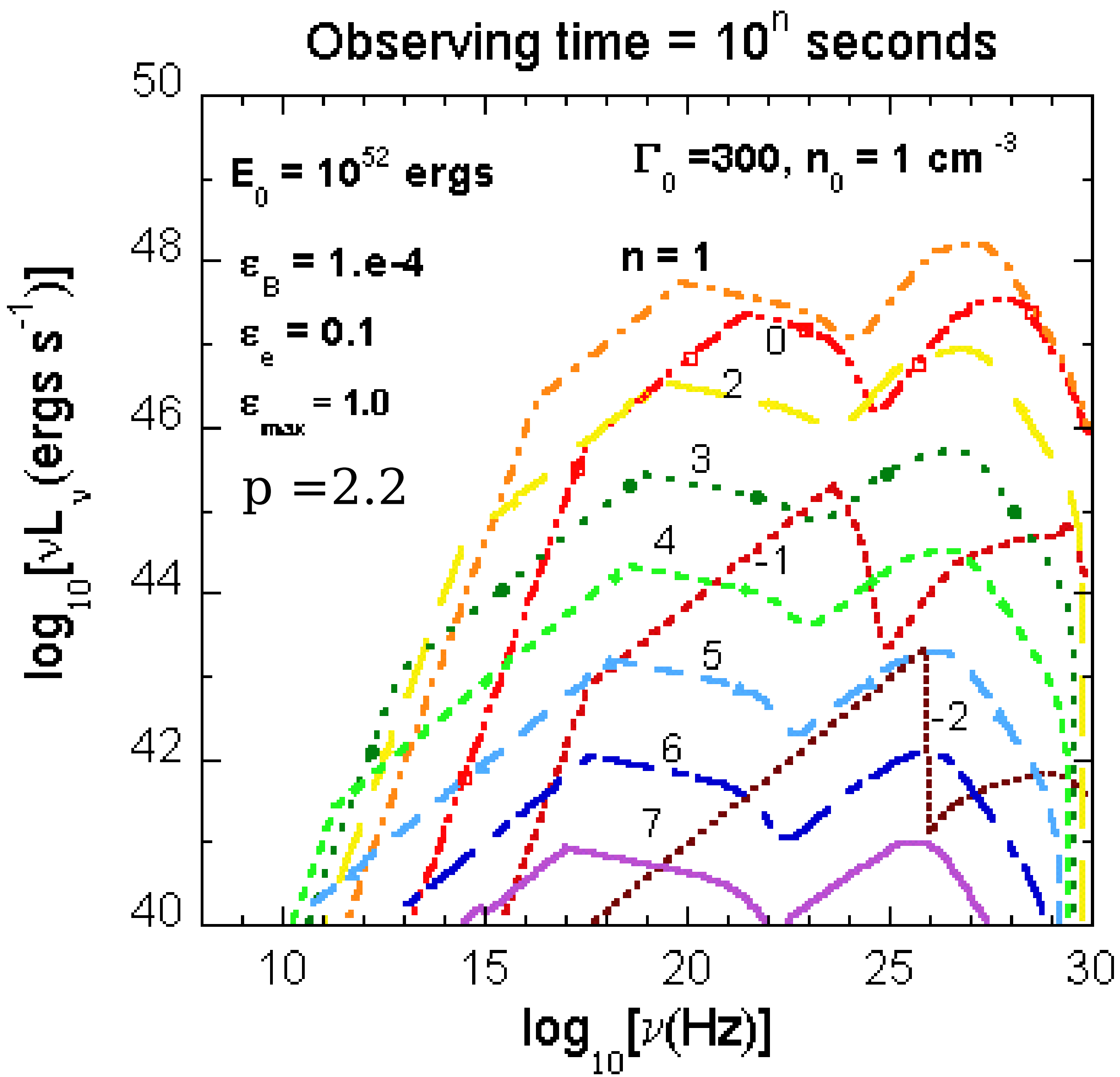


log10 t =-2.000e+00
Γ =0 =300
E0 = 1x10^54 ergs
n0 = 100 cm -3
εB = 1.e-4
εe = 0.5
p = 2.5
MeV
10 GeV
log10 [ν Lν (ergs s-1)]
log10[ν(Hz)]
52
50
48
46
44
42
40
8
12
16
20
24
28

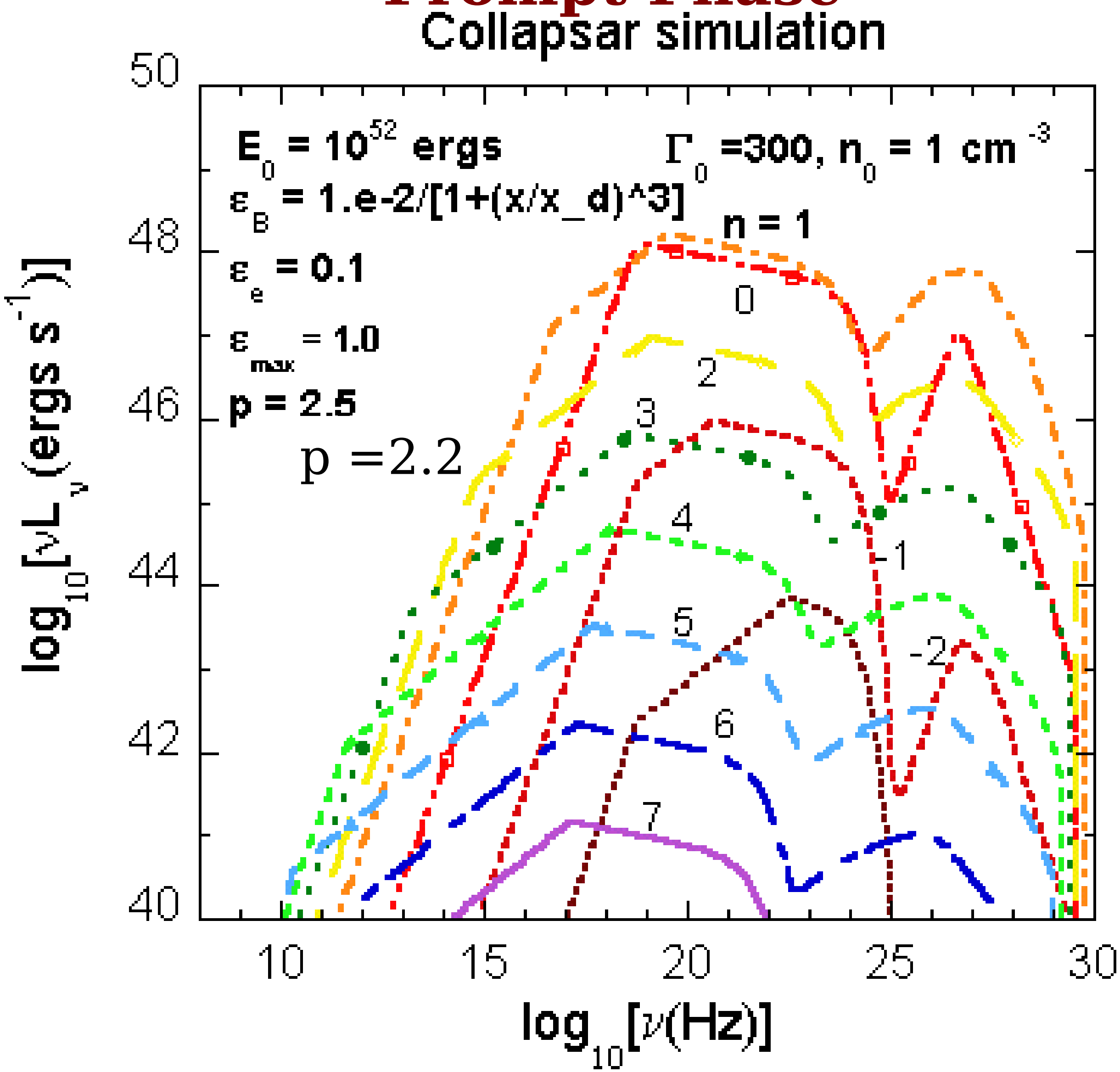
Vanilla Parameters



Vanilla Parameters with $\epsilon_B = 10^{-4}$



Simulate Collapsar Model Emission during Prompt Phase



External Radiation Field

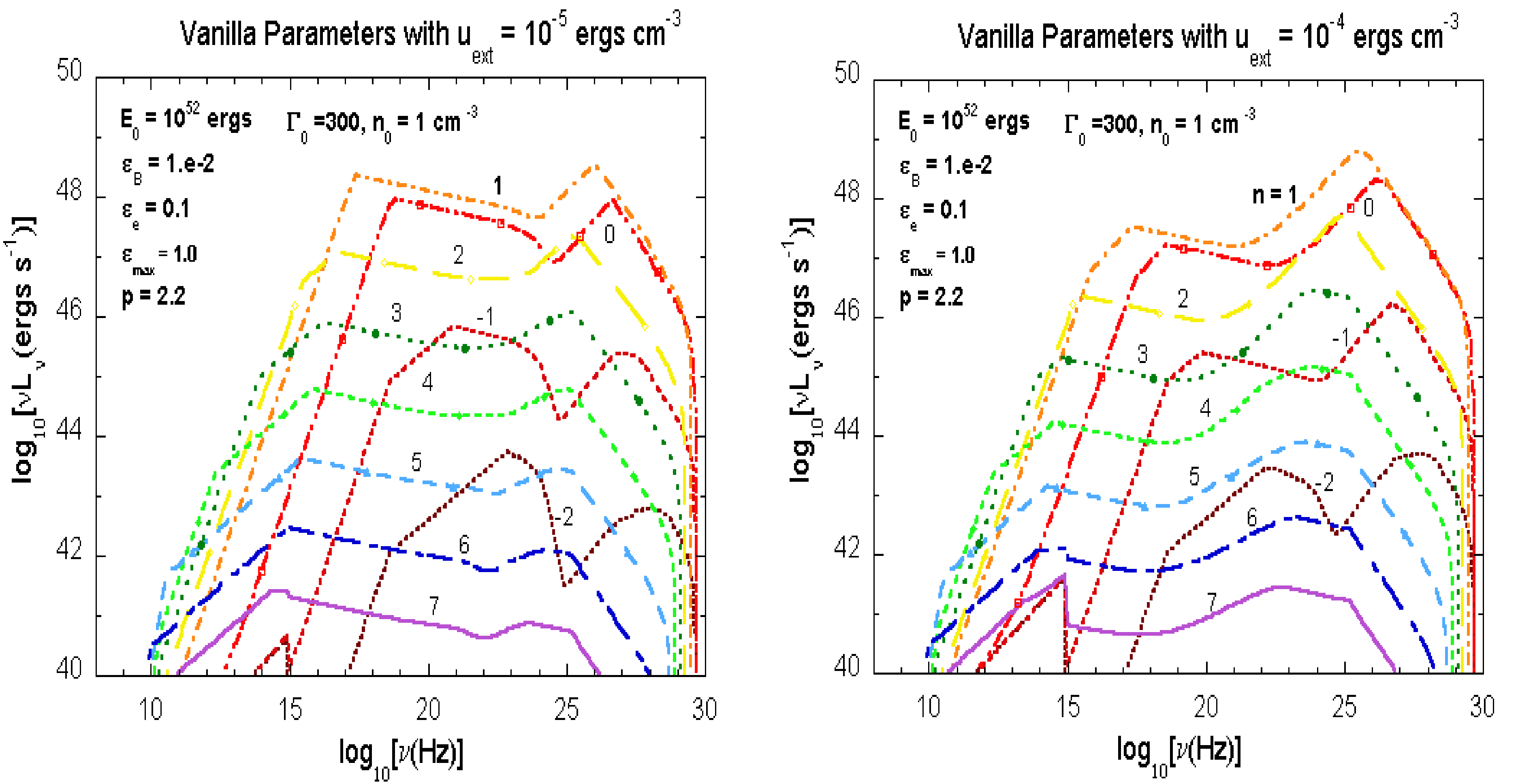
- Pre-SN Radiation Field Scattered by Surrounding Gas and Dust in Collapsar Model
- PWB Plerionic Emission in Supranova Model

$$u_{ext} \cong \frac{3}{4\pi} \frac{10^{53} E_{53}^{rad}}{(0.1 R_{-1,pc})^3} \cong 0.8 \frac{E_{53}^{rad}}{R_{-1,pc}^3} ergs\, cm^{-3}$$

- $\tau_{\gamma\gamma}$ optical depth at threshold: $(\frac{h\nu_1}{m_e c^2})(\frac{h\bar{\nu}}{m_e c^2}) \cong 2$

$$\tau_{\gamma\gamma}(\nu_1) \approx \frac{u_0 (ergs\, cm^{-3})}{h\bar{\nu}} R \sigma_T$$

External Radiation Field (no γγ transparency included)



- No γγ-transparency
- External Compton decays in concert with synchrotron photons

Are Leptonic Models Ruled out for γ-ray Emission Components in GRB 941017?

- Major difficulty is that >10 MeV γ-ray component increases while < 2MeV synchrotron component decays
- Yet to rule out reverse shock emission that increases during the progression of the GRB to provide target photons for forward shock-accelerated electrons

Nonthermal Hadronic Models in the Blast-Wave Framework

Dermer and Atoyan, PRL (2003), see poster

- High-energy neutral beam production from ultrarelativistic hadrons accelerated by GRB blast waves.
- Collapsar model: internal nonthermal synchrotron radiation is the primary target photon field. Supranova model: external pulsar-wind synchrotron radiation provides additional target photons
- Under the assumption that equal energy is injected in the form of nonthermal protons as is observed in the form of radiation (f_b = 1) GRBs are not detectable neutrino sources with km-scale neutrino detectors.

$$E_p' \approx 4\pi d_L^2 \Phi_{tot} f_b \delta^{-3}/(1+z);\ fluence\ \Phi_{tot}$$

Cosmic Rays from GRB Sources

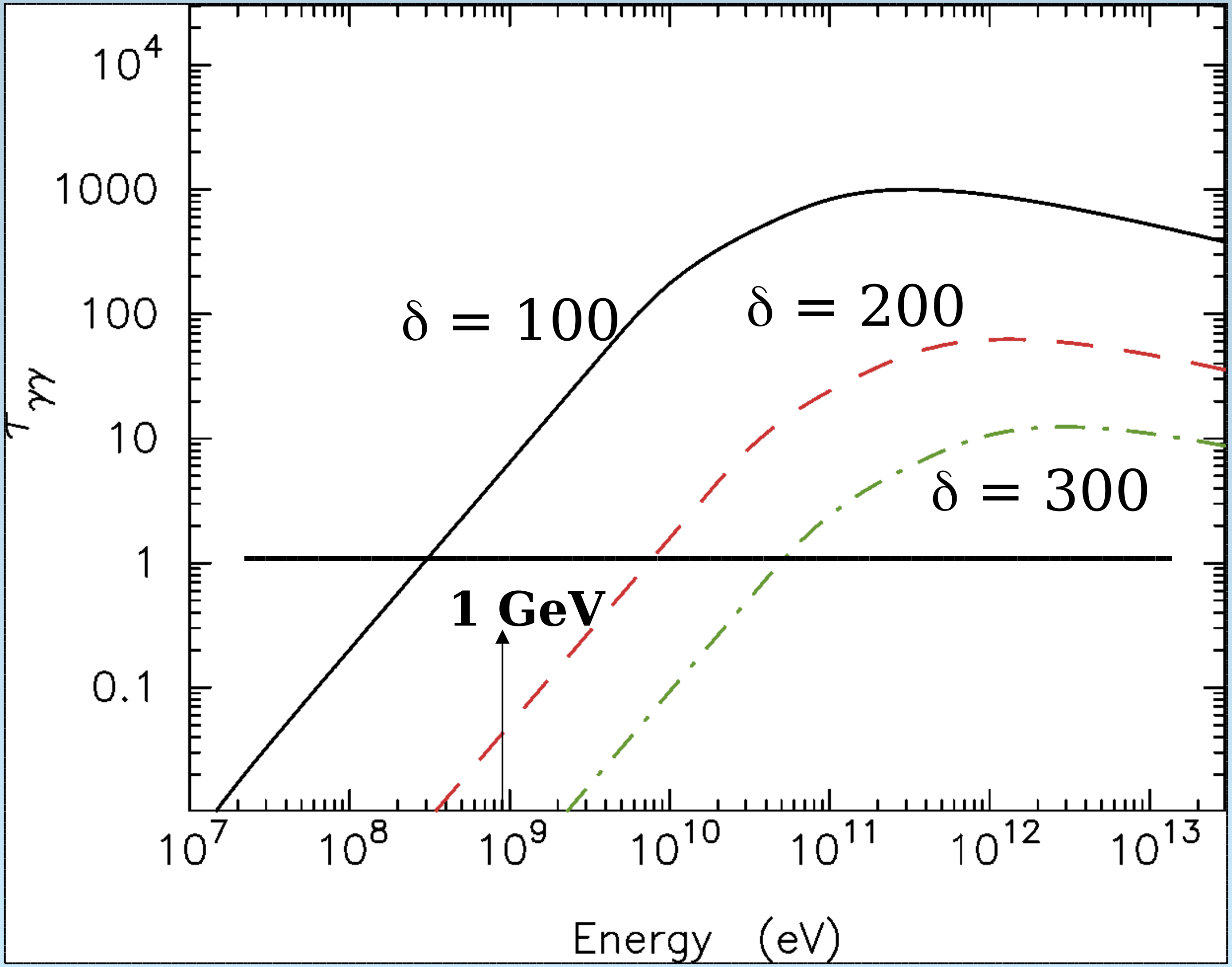
- If GRBs are hadronically dominated ($f_b >> 1$), as required in our model where high energy cosmic rays are produced by GRB sources (see talk by Wick), then we predict that km-scale neutrino telescopes such as *IceCube* could detect several GRBs per year.
- Calculate associated cascade gamma-ray spectrum from hadronic proceses in GRBs.
- Inject energy in hadrons in the form of 50 one-second pulses (t_{var}= 1 s; t_{dur} = 100 sec)

$$\Delta R' \cong t_{var} c\delta / (1+z)$$

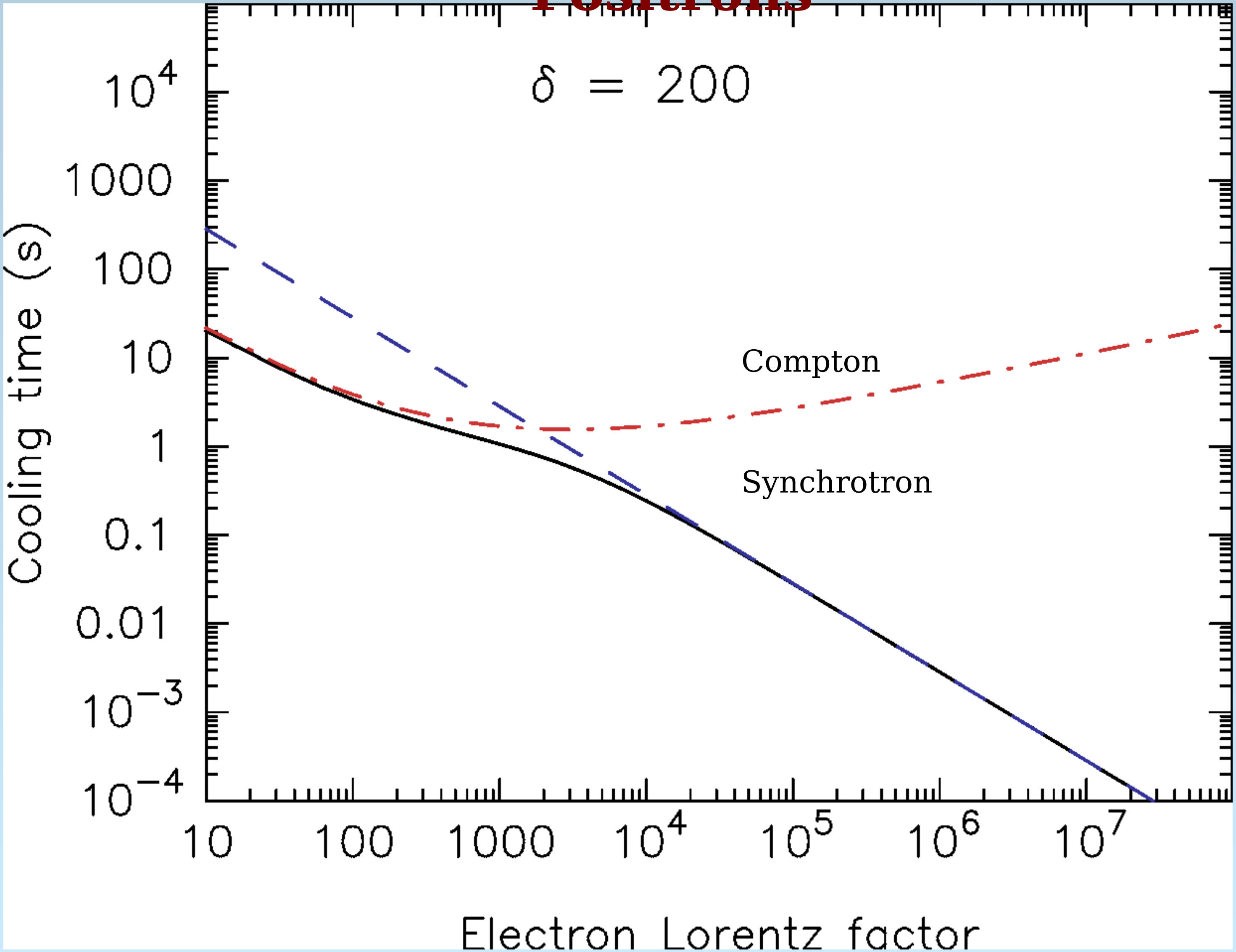
(t_{var} determines energy density of internal radiation field)

- GRB with E_{br} = 300 keV, α_{ph} = -2/3, -1.5, -2.5 in energy range E< 30 keV, 30 keV < E < 300 keV, E > 300 keV, respectively

Pair Production Optical Depth for Collapsar Model GRB

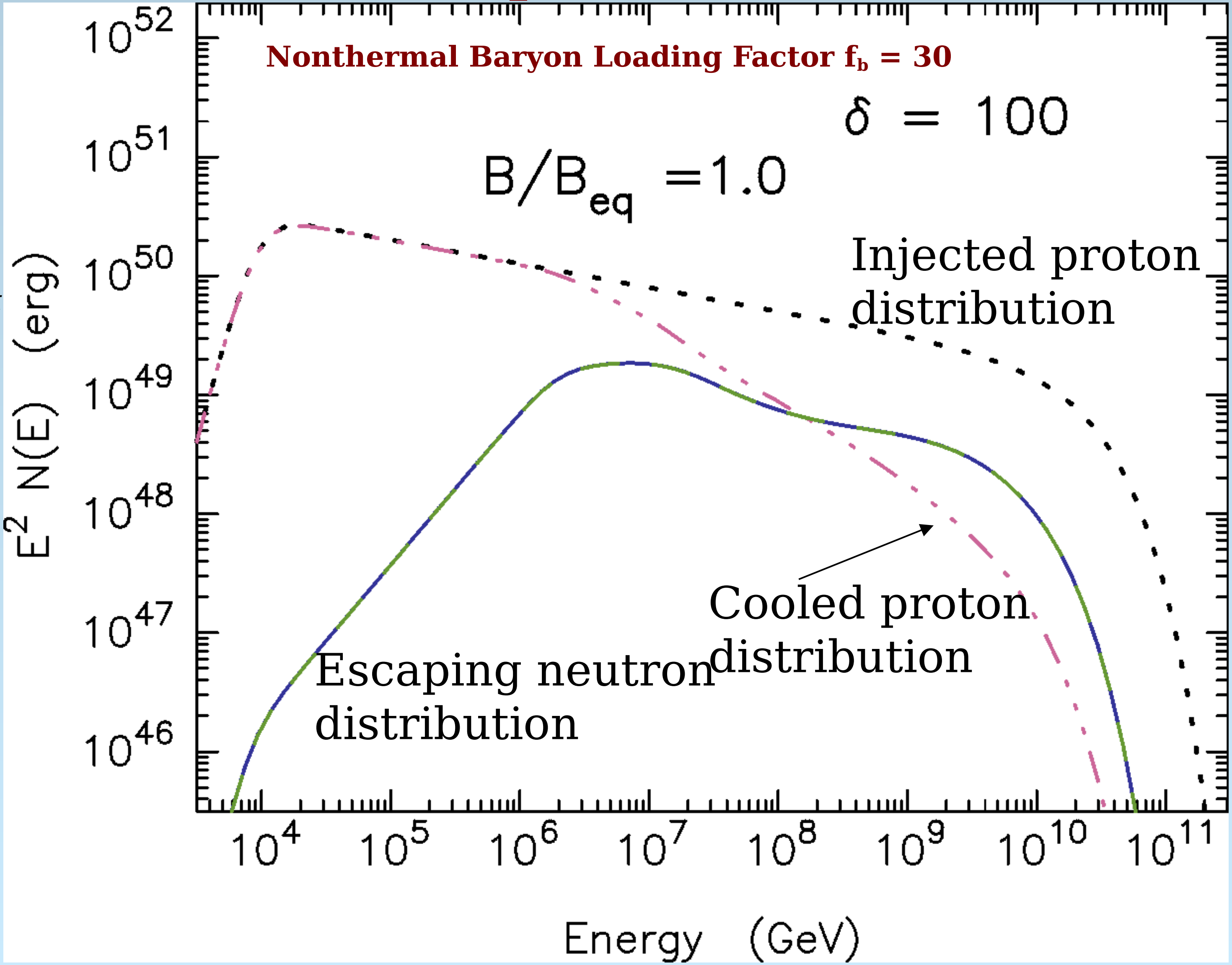


Cooling Timescales for Electrons and Positrons

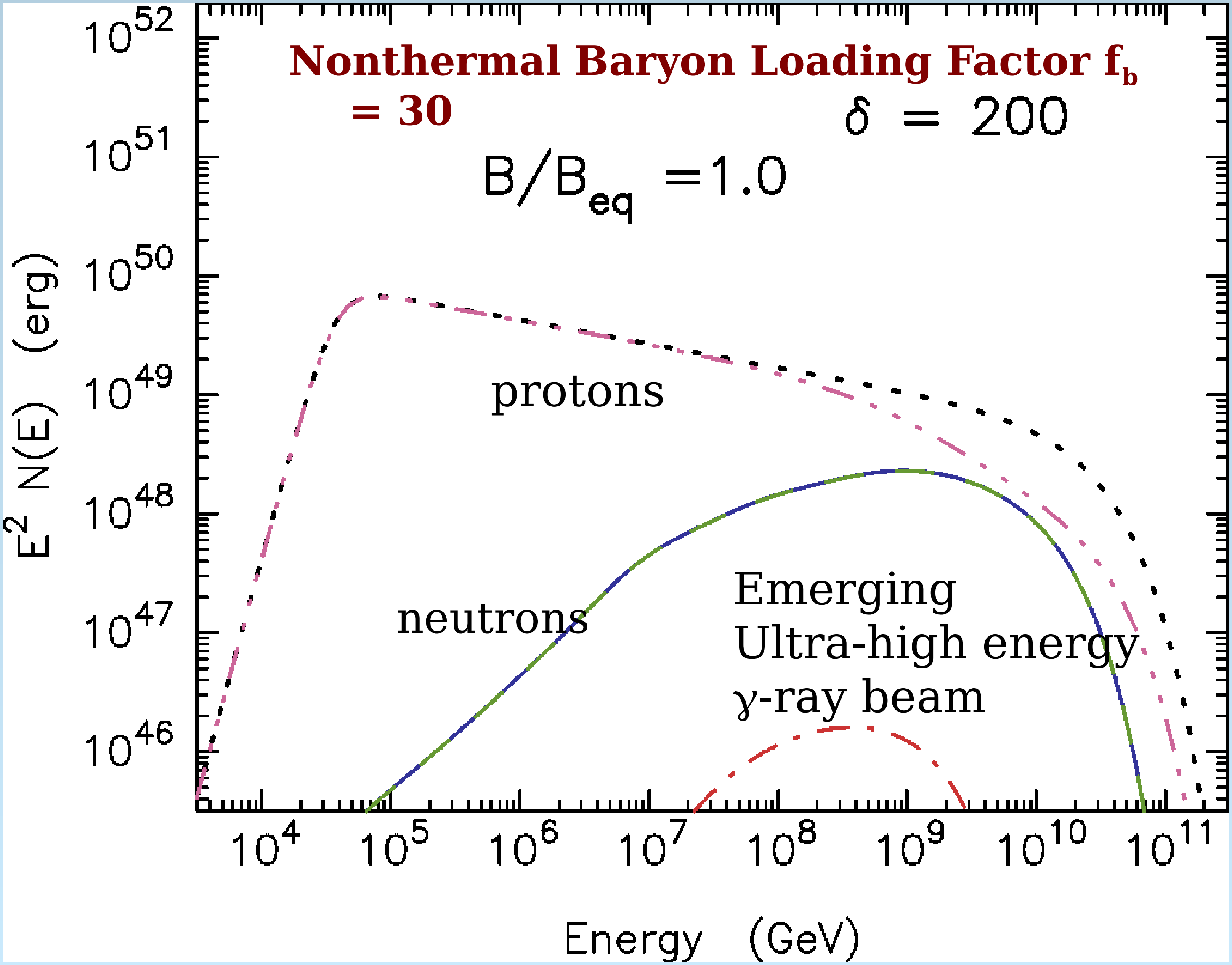


Proton Injection and Cooling Spectra

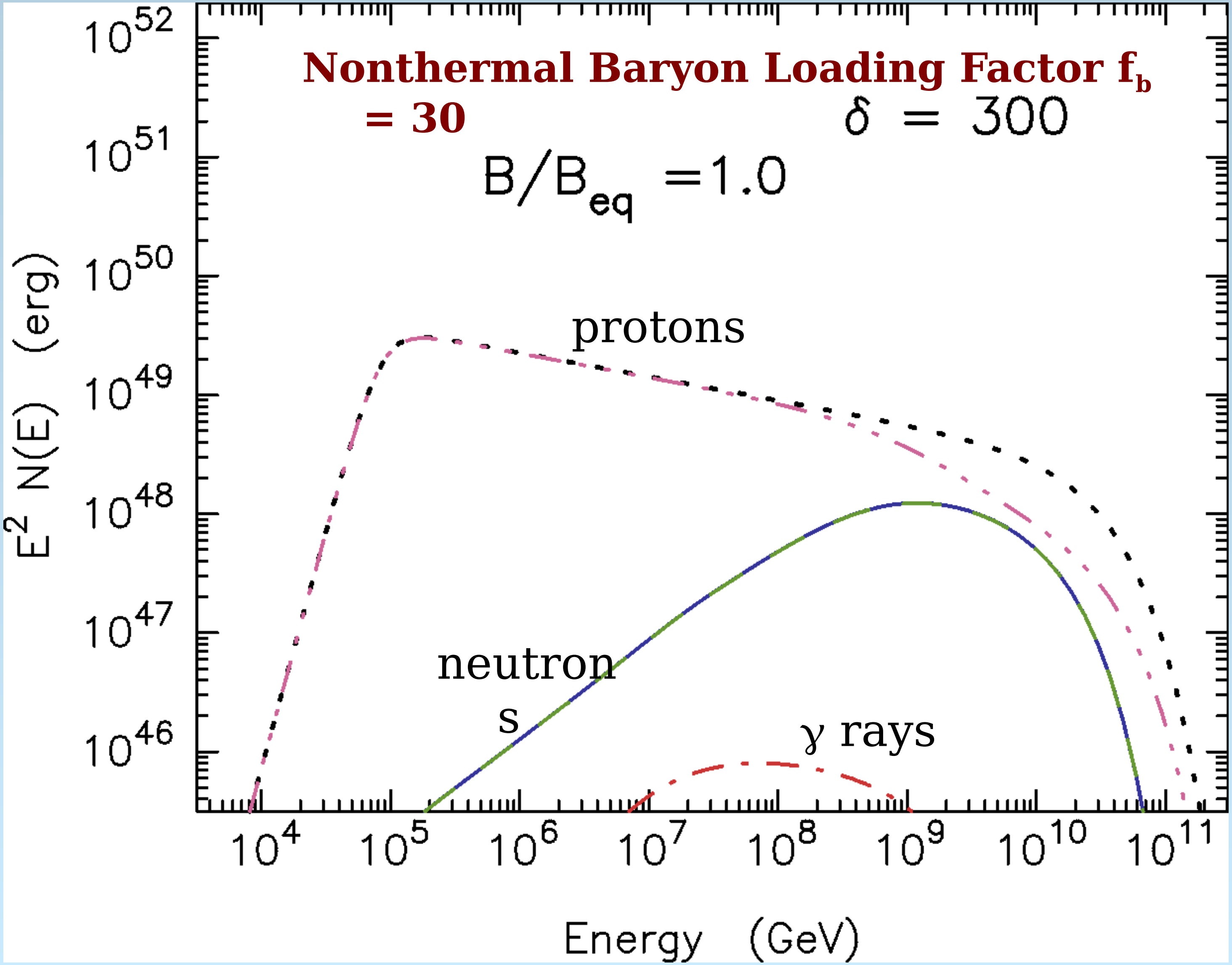
$Fluence\ \Phi_{tot}$
$= 3 \times 10^{-5}$
$ergs\ cm^{-2}$,
$z = 1$



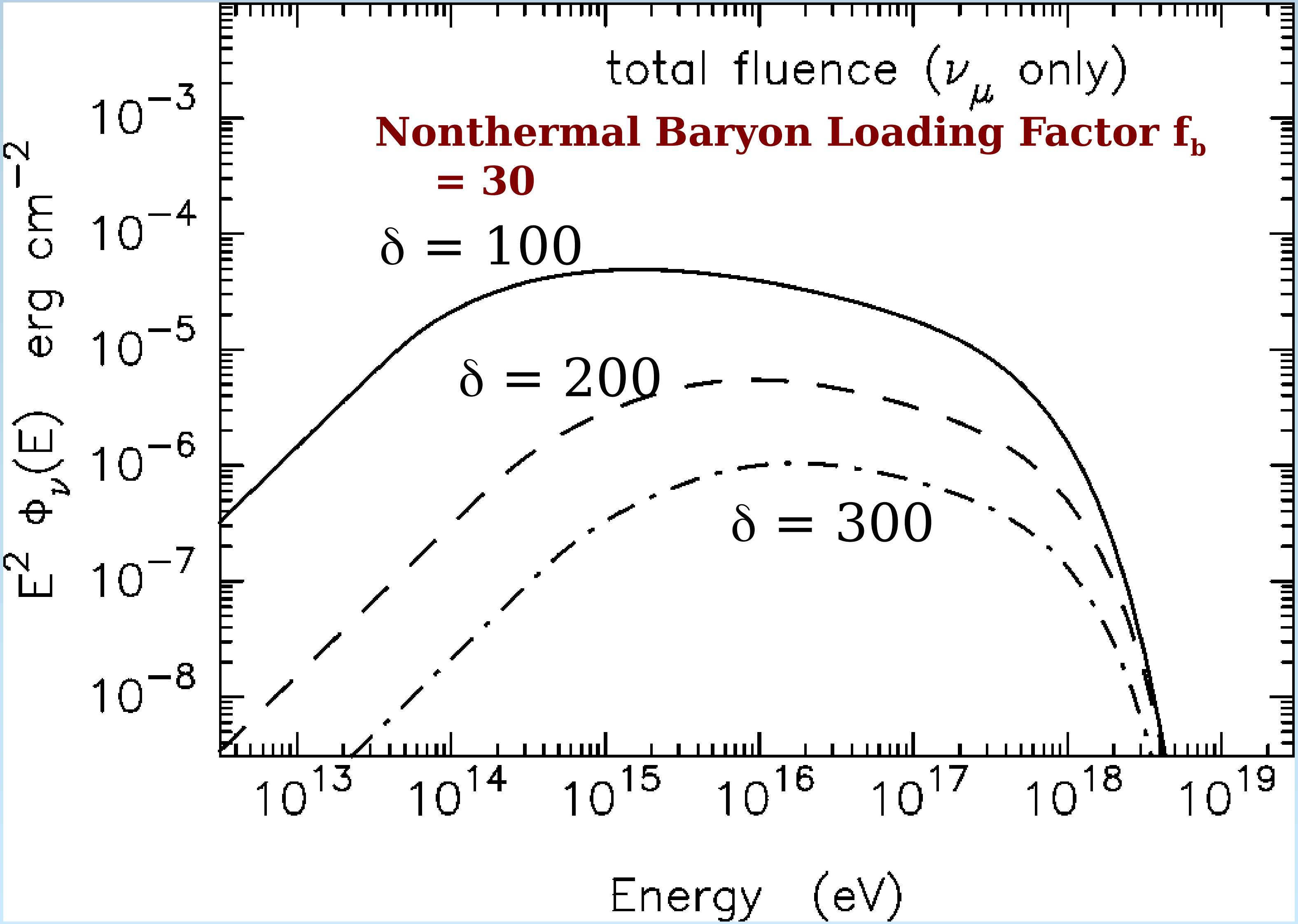
Proton Injection and Cooling Spectra (δ = 200)



Proton Injection and Cooling Spectra (δ = 300)

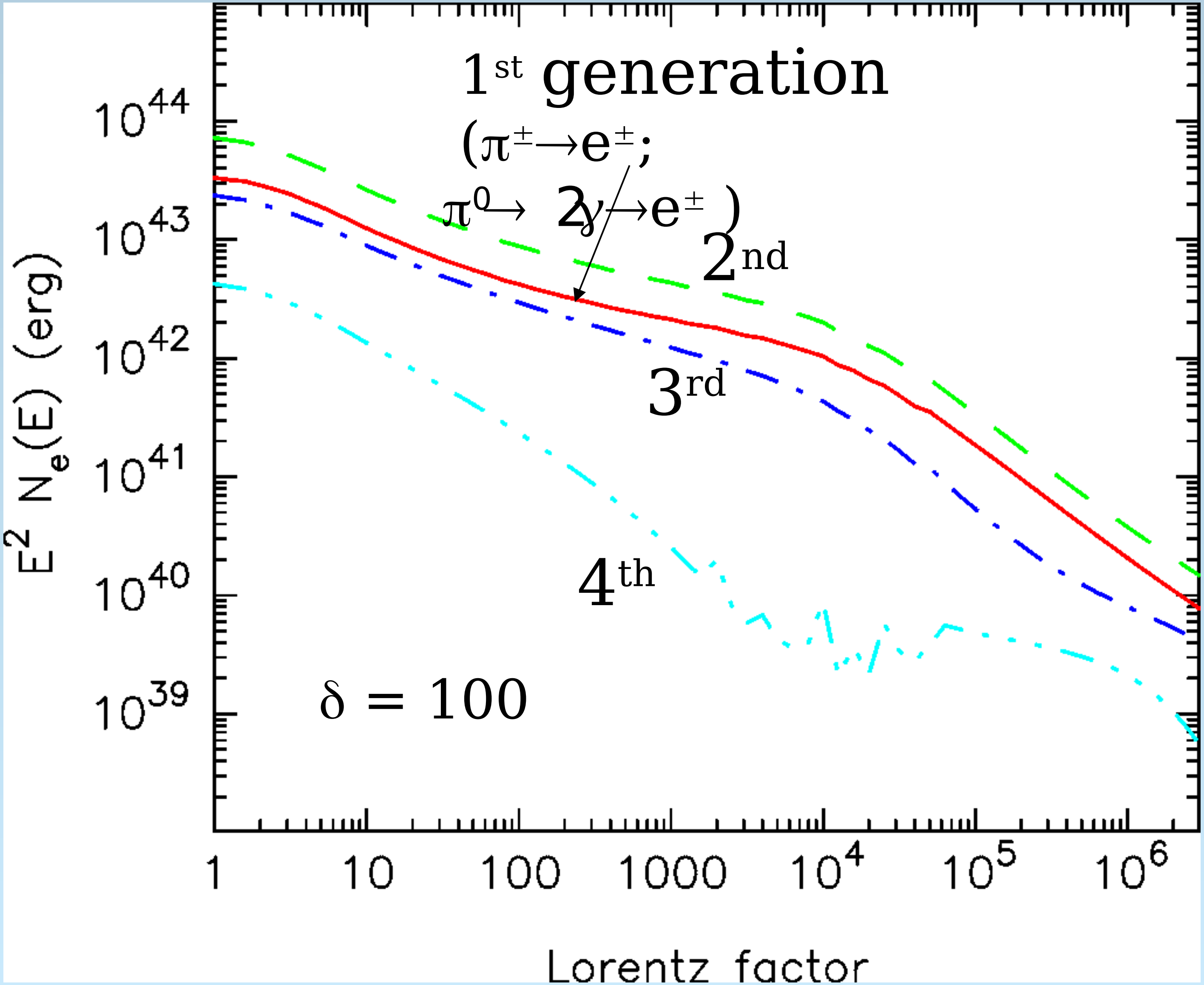


Neutrino Fluences from Collapsar Model GRB



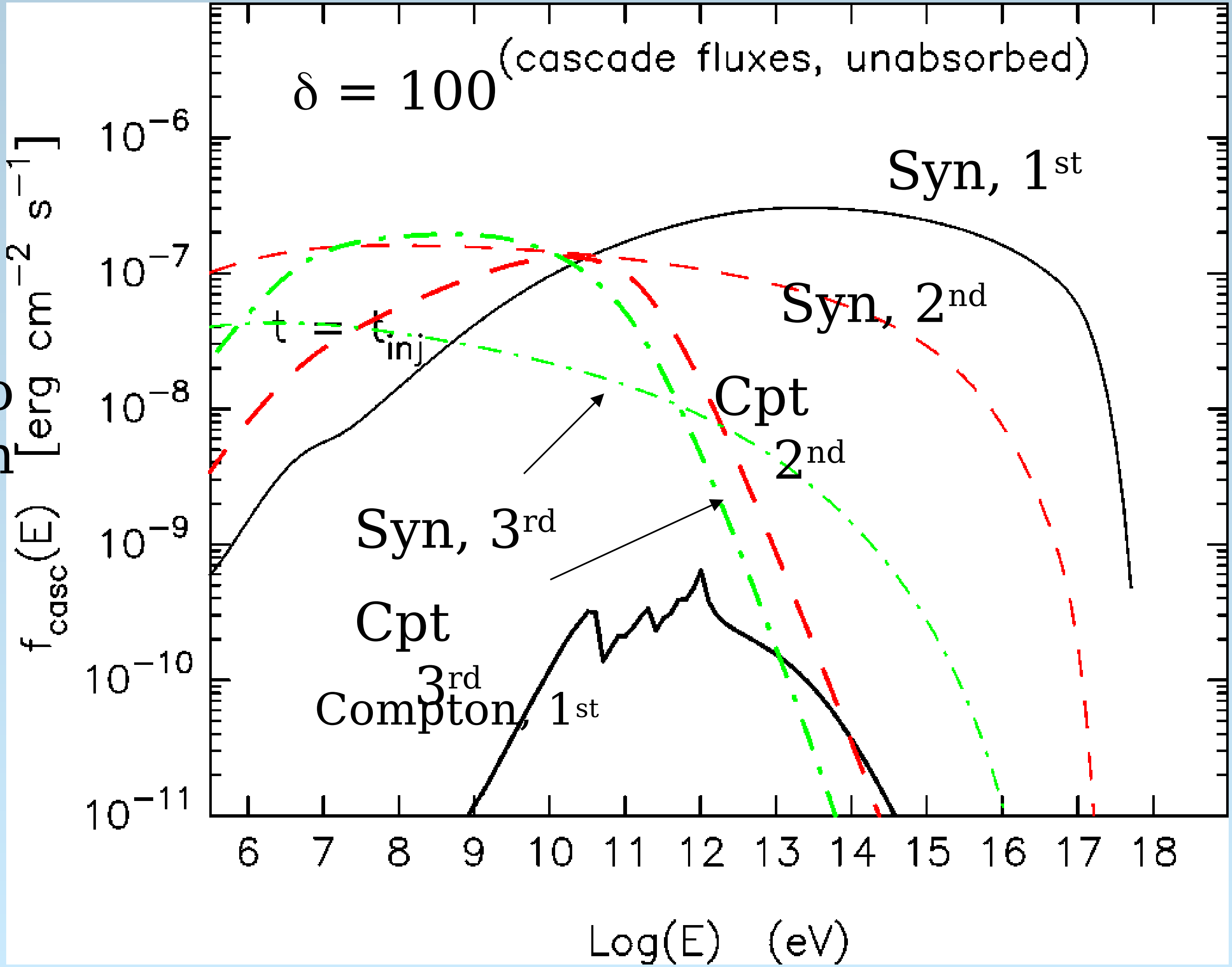
Generations of Nonthermal Leptons in Cascade Calculation

Adapt blazar neutral beam code; See Atoyan and Dermer, ApJ, 586, 79 (2003) for details



Unabsorbed Cascade Fluxes at t = t_{inj}

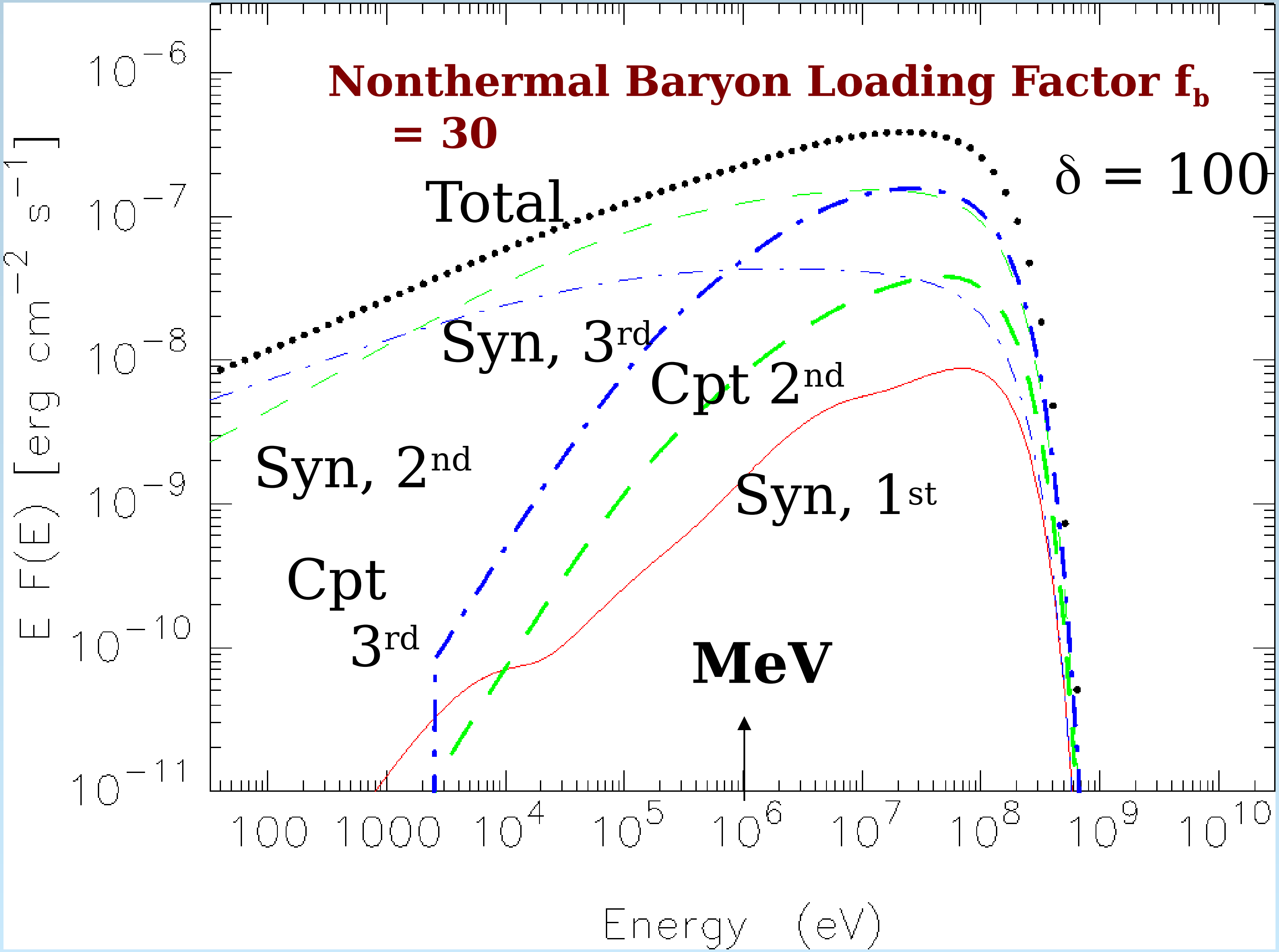
Cascade processes followed to completion



Absorbed Cascade Fluxes

Synchrotron fluxes limited if blob expands and magnetic field decays.

Compton component gives good representati on of GRB 941017



Summary

- Anomalous hard γ-ray emission component in GRB 941017 due to
  - SSC from nonthermal electrons X
  - External radiation component from nonthermal electrons X (Reverse shock target photons?)
  - Hadronic cascade contribution?
- If the latter, require hadronically dominated GRBs; would be detectable with km-scale neutrino telescopes such as *IceCube* provided $\delta < 200$: *GLAST* will constrain minimum value of δ from $\gamma\gamma$ transparency constraints (and directly observer such components)
- Observation of GRB 941017 may provide first clear clue to hadronic acceleration in GRBs